

# **Towards a Higher Level of Interoperability: Ontology Components for Command and Control Systems**

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## **ABSTRACT**

*The paper at hand argues that ontological components should be incorporated into command and control systems in order to increase their level of interoperability. The term “ontology” is explained, and capabilities of ontological components are illustrated by example. The example’s lessons are generalized and exploited for an advanced approach.*

## **1.0 INTRODUCTION**

Ongoing and future operations are and will be joint as well as multinational coalition operations. This demands command and control systems which are able to exchange information on a high level of interoperability, a level that “requires that entities be interoperable not only in the information domain, but also in the cognitive domain, so that shared awareness can be achieved” [1: p. 110]. In order to achieve such a level of interoperability, not only information has to be exchanged, but also the meaning behind it, its semantics. As an ontology provides explications of meaning, it is manifest that ontological components might enable command and control systems to achieve the desired level of interoperability.

The paper is structured as follows: Section 2 provides a definition for ontology. It also compares it with relating terms like taxonomy, data base, data model, and knowledge base. Then, in section 3, the capabilities of ontological components are illustrated by an example. A system is presented which analyzes military reports given in natural language by means of ontological processes. The analytical results are sufficient for the actualization of the underlying data base as well as for displaying the report’s content on the map. Thereafter, section 4 generalizes the insights from section 3 about the functioning and the capabilities of ontological components. These components improve information exchange among IT-systems such that interoperability is achieved even with respect to the cognitive domain. Finally, section 5 provides an outlook on a project in progress which will demonstrate the capabilities of ontological components beyond the points made.

## **2.0 ONTOLOGY**

According to the Encyclopædia Britannica, “ontology” is “the theory or study of being as such; i.e., of the basic characteristics of all reality.” However, this had been a term of philosophy, coined in the 17<sup>th</sup> century in order to denote what had originally been “metaphysics” in the ancient times. Recently, “ontology” entered the terminology of computer science. Its use now “has a different slant from the previous philosophical notions” [2: p. 174]. Ontology is defined as an explicit specification of a shared

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## Towards a Higher Level of Interoperability: Ontology Components for Command and Control Systems

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conceptualisation by Gruber [3]. It represents knowledge, especially the knowledge which human beings take for granted. The represented knowledge is restricted to a specific domain. Otherwise, it would not be manageable within an IT-system.

If an ontology represents knowledge, the question may arise, how it differs from taxonomies, data bases, data models, and knowledge bases, respectively. In general, a taxonomy is a classification of things into a hierarchy of groupings, normally used with respect to organisms. An ontology also uses a hierarchy to group objects relevant in its domain. Although, such a hierarchy may refer to many semantic relations, e.g., **part\_of**, or even mixes of them, it is wise to use the standard relation **ISA**, the subtype relation. Therefore, an ontology normally includes a taxonomy as back bone.

The objects of the domain which are grouped hierarchically construct the ontology's lexicon. Attributes are assigned to the lexicon elements. Some of these attributes take other lexicon items as value. These attributes represent relations among the objects. They can be used to represent all those semantic relations which had been rejected for defining the base hierarchy, but nevertheless are significant in the domain, like **part\_of**. Attributes are restricted with respect to the values they may take, and attributes as well as their value restrictions are inherited through the hierarchy. The choice of **ISA** as defining relation of the hierarchy permits this inheritance. In all these aspects, an ontology resembles an object-oriented data model. As the ontology is about types (classes) and not about tokens (instances), it has to be compared to a respective data model and not to a data base. Doing so, one may say, an ontology is a data model and more. For example, Dorion and Boury-Brisset [4] argue rightly that the C2IEDM [5], although not truly object-oriented, may serve as informal ontology together with its documentation. In this case, the documentation provides (or has to provide) what is missing, the explication of the semantic relationships among lexicon elements. In general, there is a set of rules or processes representing these semantic relationships. In an ontology about geometry objects, for examples, there would be the lexicon elements "square" and "rectangle." These elements would be connected in the hierarchy since square is a rectangle. There also would be attributes like "side length" and "surface area" restricted to have positive floats as values. Finally, there would be rules specifying the relationship between "side length" and "surface area."

So, ontology is more than taxonomy and also is more than data model. In order to compare ontology to a knowledge base, it can be said that a knowledge base is to a data base what an ontology is to a data model. The knowledge base is about token or instances but not about classes. It provides explications of semantic relationships on the individual level but not on the general level as an ontology does (cf. [6] for more details).

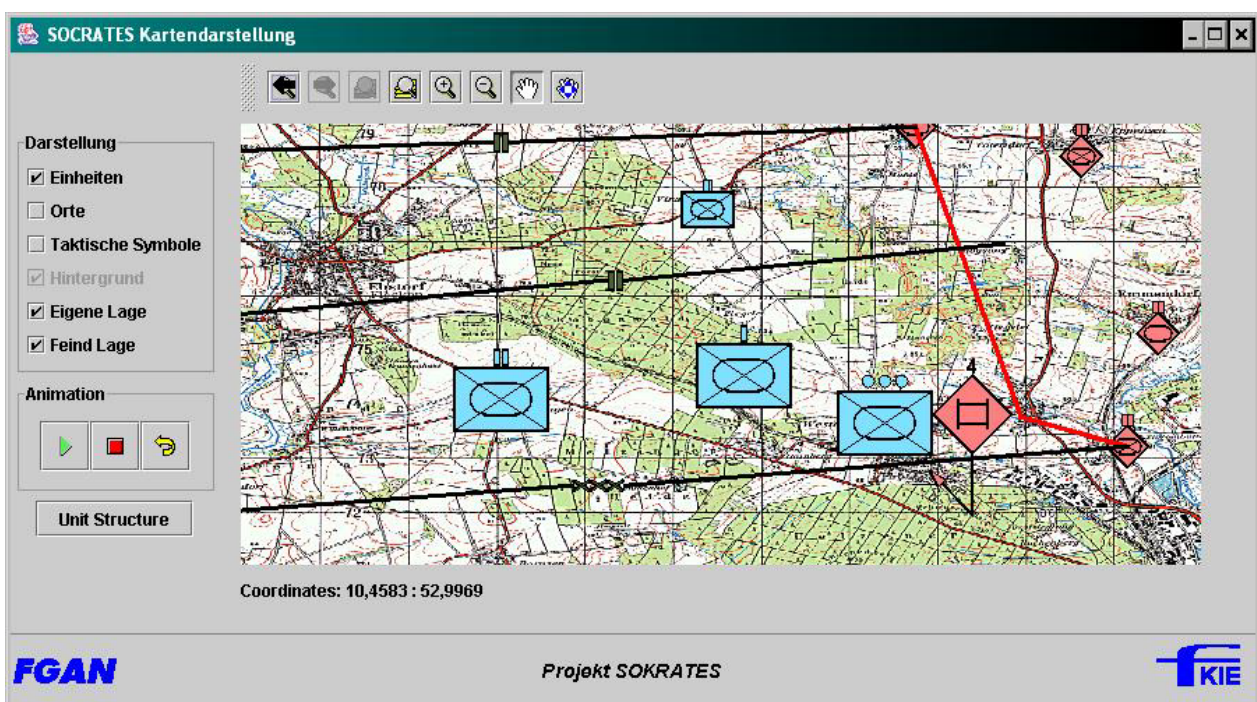
In summary, an ontology provides all the knowledge that has to be known in an explicit format such that this knowledge is available for automatic semantic processing. In the following, it is therefore argued that command and control systems should be equipped with ontological components in order to enable them for semantic processing. This is a pre-condition for interoperability on a higher level.

### 3.0 EXAMPLE

The capabilities of an ontological component can best be illustrated by example. In order to evaluate the ontological approach, we developed a report processing system called "the Sokrates system" and realized it as a prototype. The system is meant to process information brought in by real-world military reports given in natural language, and the prototype deals with reports of moving actions like "*Five Bradlyland howitzers moving from Nederveert to Helmond via Someren*" or "*Four hostile battle tanks approaching*." It also processes position reports like "*Arrived at 31UFT785235*." Processing within the system starts with a linguistic analysis of the report by means of information extraction (cf. [7]). Information extraction provides a formal representation of the conveyed information as result. This formal representation is provided in the form of a *feature structure*, the standard representation format used by language

processing systems in the field of computer linguistics propagated by Shieber [8]. More details about the information extraction module used in the Sokrates project can be found in [9].

The feature structure resulting from information extraction has to be augmented to allow downstream processes like displaying the information on a map or the actualization of the underlying data base. This augmentation is the task of an ontological component realized as module within the Sokrates system. The module runs ontological processes. These processes operate on a hierarchy of battle space objects closely related to the C2IEDM (cf. [10] for more details about the battle space ontology used in the Sokrates system). The hierarchy constitutes the ontology's lexicon as described in section 2.0, and the processes represent semantic relationships holding among the battle space objects. They therefore can be used to determine information which is not explicitly mentioned in the reports (and thus not represented in the information extraction's result), but is inferable by semantic means. Running an ontological process results in a new or more specific entry of the feature structure.



**Figure 1: The visualization of the example report by the Sokrates system**

The ontological processes can be divided into simple completions, obligatory calculations, and facultative calculations. In the following, these subcategories are illustrated with respect to the example report "Four hostile battle tanks approaching." Quoted as *simple completions* are those processes which add to the feature structure by exploiting ontology's hierarchy or the underlying data base directly. For example, according to ontology's lexicon, tanks are equipment. An entry listing the graphical attributes of the respective APP-6A symbol (cf. [11]) is added. By the way, in accordance to the APP-6A, but in contrast to the C2IEDM, the ontology categorizes battle tanks not only as land weapons but also as vehicles to allow vehicle-based inferences. An *obligatory calculation* provides a value required by one of the downstream processes (visualization or data base actualization) which cannot simply be looked up consulting ontology's lexicon or the data base. With respect to the example, two objects have to be displayed on the map, the report's sender and the hostile battle tanks. The position of the sender should be known either directly by GPS or via data bank. The position of the hostile tanks is a different matter, especially as they are moving. However, the verb "approaching" implies that the movement of these tanks is directed at the position of the sender. Thus, what is still needed is the direction from where the tanks approach. In order



## Towards a Higher Level of Interoperability: Ontology Components for Command and Control Systems

to determine it, an ontological process first calculates the point of the FEBA (forward edge of battle area) which is nearest to the sender. Then, it is assumed that the hostile tanks approach from there. Figure 1 shows the result of the calculation as it is displayed on the map. Please notice that Sokrates is a German system and therefore in fact processes “*Vier feindliche Kampfpanzer in Zufahrt*”, the German equivalent to the given example report.

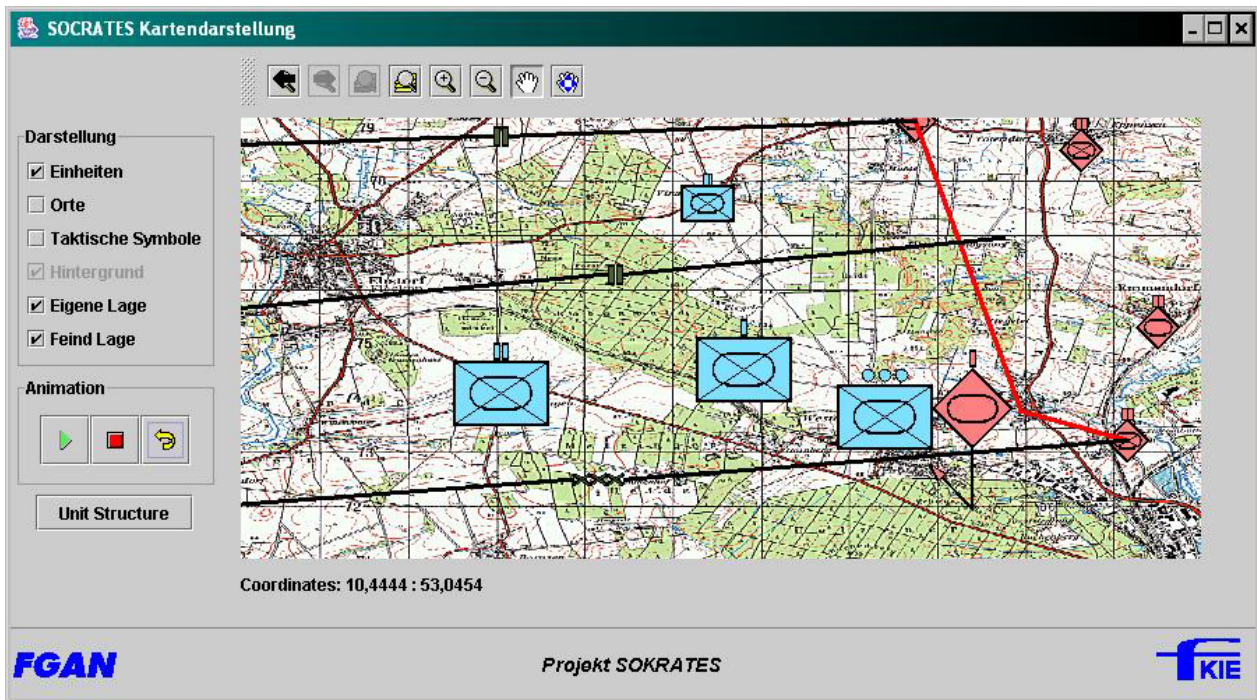


Figure 2: The visualization of the example report, unit determination activated

A *facultative calculation* is a process, the system's operator is allowed to activate or deactivate as required. Such a facultative process is the unit determination process. It identifies objects of type vehicle and of type weapon system like the battle tanks in the example report. It then checks which kinds of units hold such objects as (principle) equipment. If it finds a compatible unit type, it adds it to the formal representation as the equipment's operating unit. As a result, a respective symbol will appear on the map. As can be seen in figure 2, with respect to the example report, the process reckons that the four battle tanks will be operated by a battle tank unit. Because there are four tanks the unit is supposed to be at least of platoon size. So, if this process is activated the visualization displays the symbol for “unit combat armor, hostile” together with the size indicator for platoon instead of the symbol for “equipment, armoured tank, hostile” together with quantity indication “4.”

## 4.0 INTEROPERABILITY

Two systems which are connected physically are able to exchange data. This is the pre-condition for any interoperability, but to exchange data is not sufficient for the exchange of information. The most obvious way to enable systems to exchange and thus to share information is to use the same data model, e.g., the C2IEDM. But even in this beneficial case, the quality of information shared counts. Only the exchange of high quality information ensures that the sense of the information exchanged will also be communicated, that a common operational picture will emerge, and that the systems' operators will reach a shared situational awareness and, as a consequence, will collaborate effectively. Only the exchange of high quality information ensures a higher level of interoperability [1: p. 109].

As had been shown by the example of the Sokrates system, ontology components significantly add to the quality of information shared. To the Sokrates system, the source information is given in natural language. During the first step of processing, it is transformed into a formal representation on the basis of the standard data model. The ontology component then completes this representation, the feature structure. The completion is not an improvement of the information with respect to quantity, only. It means also an improvement with respect to quality because the ontological processes eliminate vague and ambiguous terms within the representation. The result is much more explicit. Explicitness ensures that the information will be interpreted identically by anyone and any system, and so interoperability reaches the cognitive level.

The Sokrates system is designed for the task that “a system” using natural language for communication sends information to a command and control system having the C2IEDM as data model. But, in joint as well as in coalition force operations, different command and control systems have to exchange information. Quite often, the beneficial case that all these systems use the C2IEDM as data model does not hold. However, these kind of environments are only generalizations of the situation the Sokrates system operates in. The consequences of a perception like this one have in theory already been described [12]. The cases in question can be tackled by ontological means along the ideas developed in [13]. Information to be exchanged is transformed into a formal representation on the basis of the C2IEDM. The representation is enriched by ontological processes and becomes more explicit during this step. It then is interpreted by the receiver system with respect to its underlying data model. Again, ontological components help to elaborate the interpretation.

## 5.0 OUTLOOK

At present, we are developing and testing a prototype to evaluate the approach. The test situation is as follows. An army command and control system based on the C2IEDM has to exchange information with an air force command and control system based on a special air force data model [14] in order to coordinate a closed air support requested. This project exploits the tools developed in the Sokrates project for the interaction. Both systems have been equipped with their own ontological component. Hierarchy-wise, these components originate from a core ontology. Both are aligned with their respective underlying data model. Process-wise, the Sokrates processes are taken and transformed such that incoming data is augmented and explicated towards a representation ideal for a system’s own data base. The feature structure representation as resulted from information extraction in Sokrates serves as reference language. Like in the original Sokrates system, this architecture allows an information exchange between the two systems which taps into a level of interoperability resident in the cognitive domain.

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# Preliminary Remarks

Multinational coalition operations demand command and control systems which are able to **exchange information**

on a **high level of interoperability**

“so that shared awareness can be achieved.”

Alberts & Hayes: Power to the Edge

# Preliminary Remarks

## Interoperability Degrees

(NATO Interoperability Directive)

- Degree 0: Isolated I. (= no interoperability)
- Degree 1: Connected I. (= physically connected)
- Degree 2: Functional I. (shared data formats)
- Degree 3: Domain I. (shared data model)\*
- Degree 4: Enterprise I. (“one system”)

# Preliminary Remarks

## Interoperability Degrees

(NATO Interoperability Directive)

- Degree 0: Isolated I. (= no interoperability)
- Degree 1: Connected I. (= data interoperability)
- Degree 2: Functional I. (= information interoperability)
- Degree 3: Domain I. (= semantic interoperability)
- Degree 4: Enterprise I. (= pragmatic interoperability)

# Structure of the Talk

- Preliminary Remarks
- Definition: Ontology
- Example: The SOKRATES System
- What can be learned from the example
- Outlook

# Ontology

Encyclopædia Britannica [philosophical definition]:

*An ontology is “the **theory or study of being as such**; i.e., of the basic characteristics of all reality.”*

Gruber (1993) [AI-definition]:

*“An ontology is an **explicit specification of a shared conceptualization.**”*



# Ontology

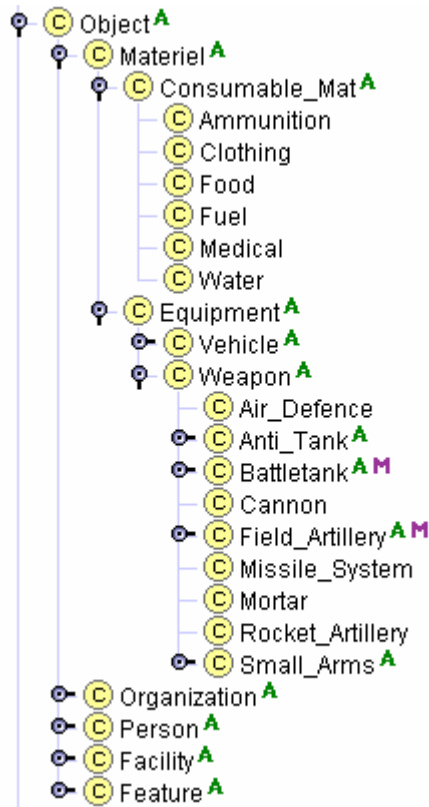
**Ontological components** have to represent the relevant knowledge about the domain in question.

The domain in question is in our case a military one. In particular, there has to be knowledge

- about the the C2 process,
- about the battle space,
- ...
- about (the flow of) time,
- ...

# Ontology

ontology = taxonomy + associated attribute-value pairs + rules



Class

Infantry\_mechanized

Direct Insts

- 2./PzGrenBtl332
- 2./PzGrenBtl332-ZugB
- 2./PzGrenBtl332-ZugC
- 2./PzGrenBtl332-ZugD
- 3./PzGrenBtl332
- 3./PzGrenBtl332-ZugB
- 3./PzGrenBtl332-ZugC
- 4./PzGrenBtl332
- 5./PzGrenBtl332
- 5./PzGrenBtl332-ZugB
- 5./PzGrenBtl332-ZugC
- 5./PzGrenBtl332-ZugD
- 5./PzGrenBtl92
- 5./PzGrenBtl92-ZugD
- MIR43
- MIR44
- PzGrenBtl332
- PzGrenBtl92

5./PzGrenBtl332 (type=Infantry\_mechanized, name=battle)

Name

5./PzGrenBtl332

Abbreviated Name

Located

ND-9979-7437

Forefront

Dummy Indicator

90

Size

COY

Size Nr

3

Unit Category

COMBAT

Arm Category

INF

# Example:

## The SOKRATES-System for Report Processing

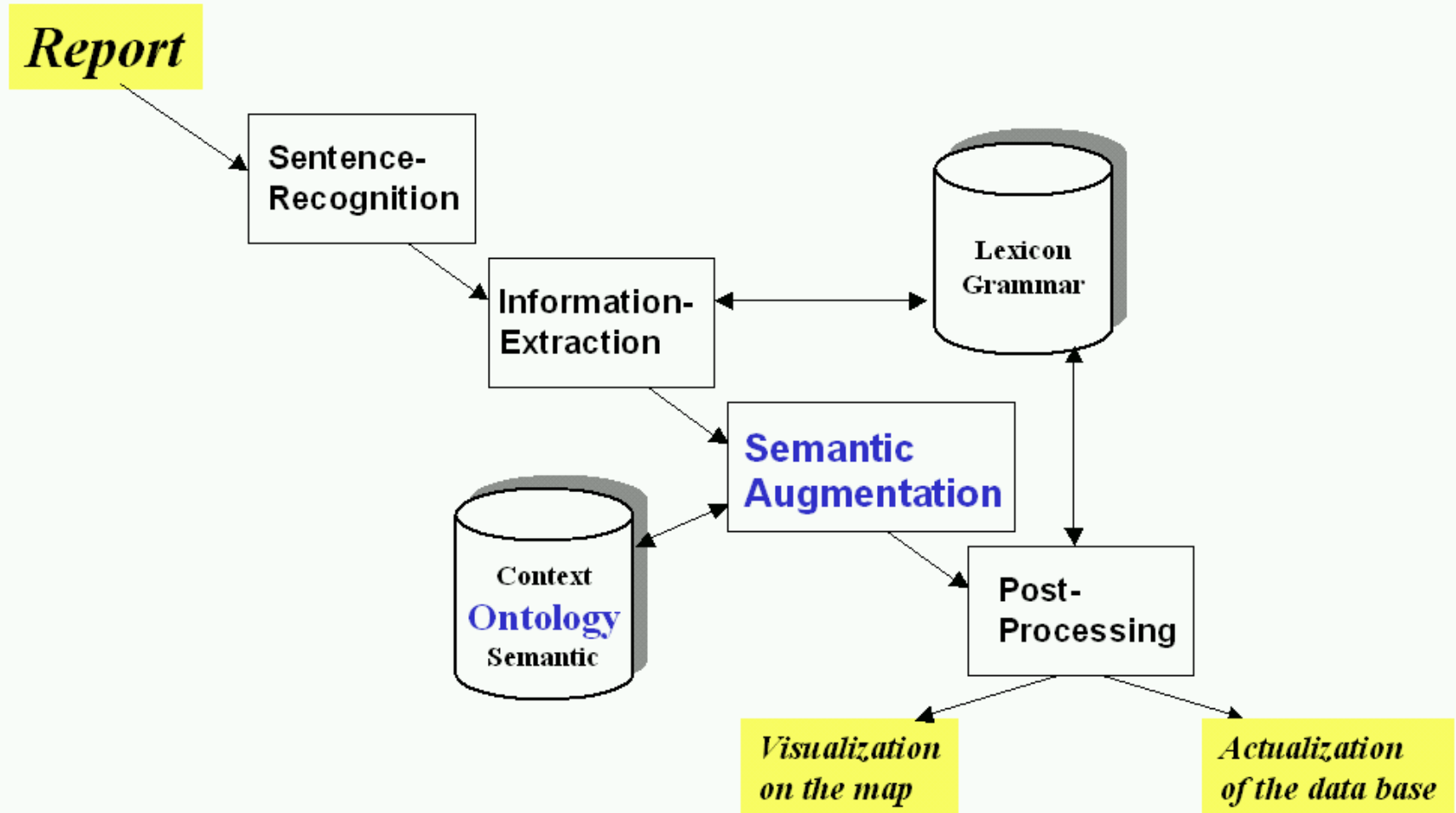
Input:            reports written in natural language

- *Five hostile battle tanks approaching.*
- *Five Bradyland howitzers moving  
from Nederveert to Helmond via Someren.*
- *Arrived at 31UFT785235 .*

Output:

- visualization of the report's content on a map
- insertion of the content into a C2IEDM data base

# Example: The SOKRATES-System for Report Processing



# Example:

## The SOKRATES-System for Report Processing

### Information Extraction

transforms the report into a formal representation.

**Semantic Augmentation** — **ontological component**  
adds information to the representation

### Post-Processing

visualizes the resulting content on a map and  
stores the resulting content in a C2IEDM data base.



# Example:

## The SOKRATES-System for Report Processing

Platoon B: *4 hostile battle tanks approaching.*



**Information  
Extraction**  
transforms  
**report**  
into **formal  
representation.**

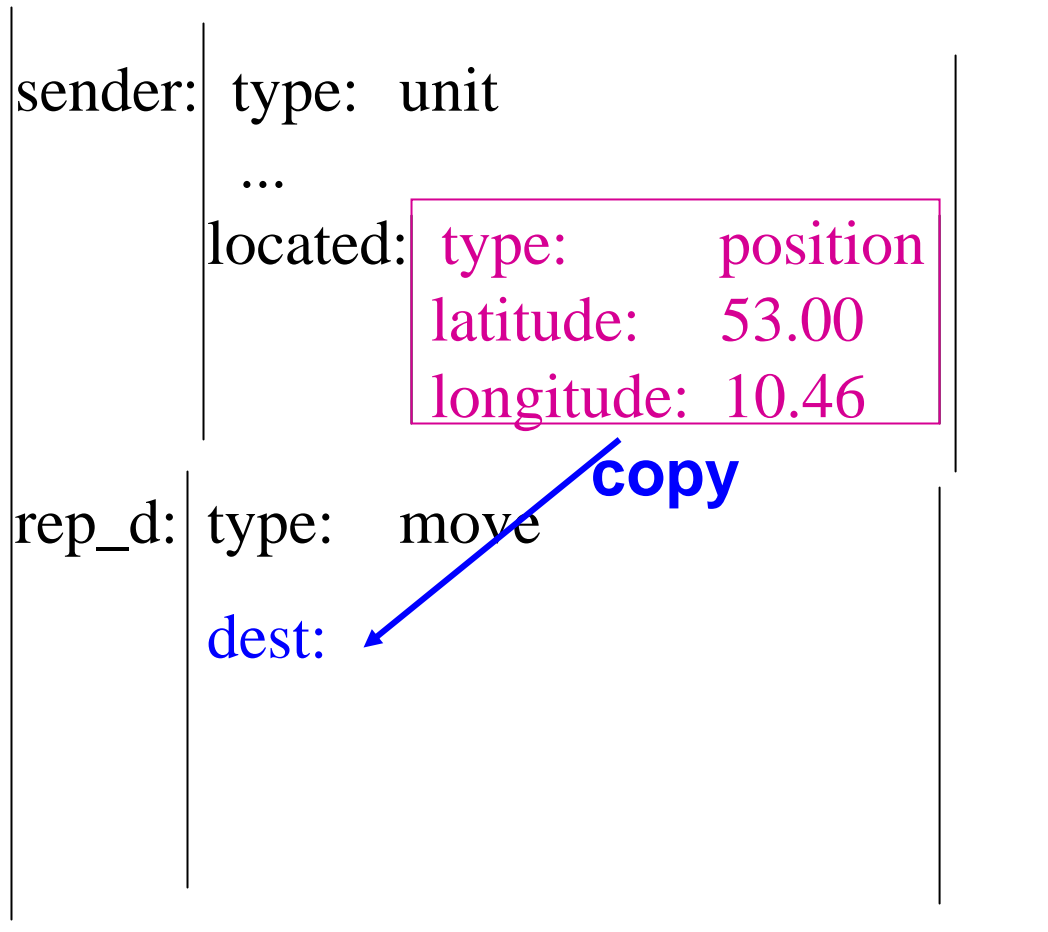
type:	report								
sender:	...								
reporting_data:	<table><tr><td>type:</td><td>move</td></tr><tr><td>theme:</td><td><table><tr><td>type:</td><td>battletank</td></tr><tr><td>count:</td><td>3</td></tr></table></td></tr></table>	type:	move	theme:	<table><tr><td>type:</td><td>battletank</td></tr><tr><td>count:</td><td>3</td></tr></table>	type:	battletank	count:	3
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type:	battletank								
count:	3								

# Example:

## The SOKRATES-System for Report Processing

Platoon B:  
*4 hostile battle tanks  
approaching.*

**Semantic Augmentation**  
adds to the representation  
(here: adding of  
the move's destination).



# Example:

## The SOKRATES-System for Report Processing

ontological rule:

set\_value(M,[rep\_d,dest],**L**):-


get\_value(M,[rep\_d,type],move),  
get\_value(M,[rep\_d,subcat],approach),  
get\_value(M,[rep\_d,agent,hostility],hostile),  
get\_value(M,[sender,located],**L**).

↑            ↑            ↑  
matrix    path    value

sender:	type: unit
	...
	located: <b>L</b>

rep_d:	type: move
	dest:



# Example:

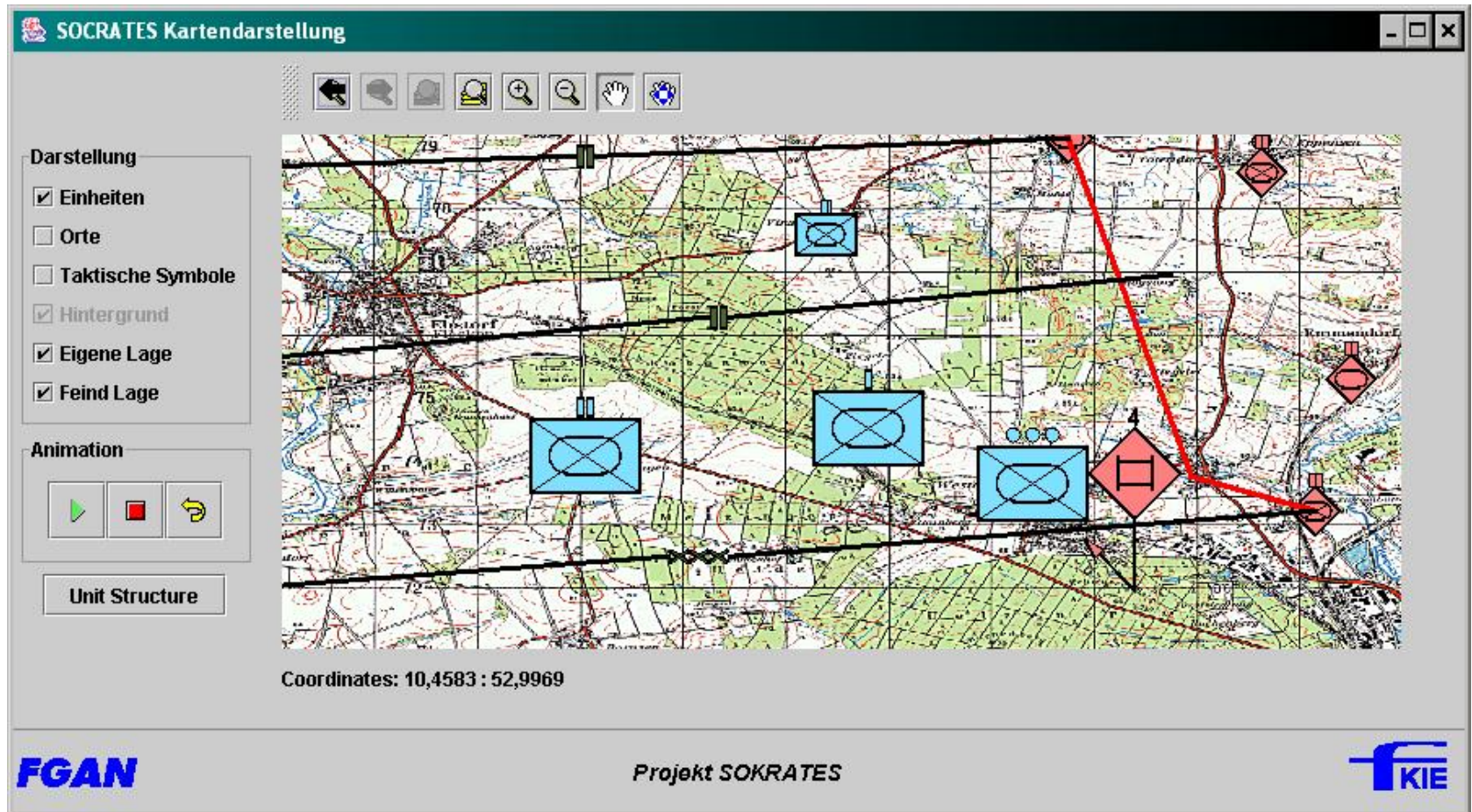
## The SOKRATES-System for Report Processing

Platoon B:  
*4 hostile battle tanks  
approaching.*

**Semantic Augmentation**  
adds to the representation  
(here: adding of  
the move's destination).

sender:	type: unit	
	...	
	located:	type: position
		latitude: 53.00
		longitude: 10.46
rep_d:	type: move	
	dest:	type: position
		latitude: 53.00
		longitude: 10.46

# Example: The SOKRATES-System for Report Processing



Platoon B: 4 hostile battle tanks approaching.



# Example:

## The SOKRATES-System for Report Processing

reporting\_data:

type: move

agent:

**type: unit**

**cat: combat**

**arm\_cat: armour**

**mobility : Indtrc**

**size: plt**

hostility: hostile

theme: type: battletank

...

Platoon B:  
*4 hostile battle tanks  
approaching.*

**Semantic Augmentation**  
adds to the representation  
(here unit determination).

# Example:

## The SOKRATES-System for Report Processing

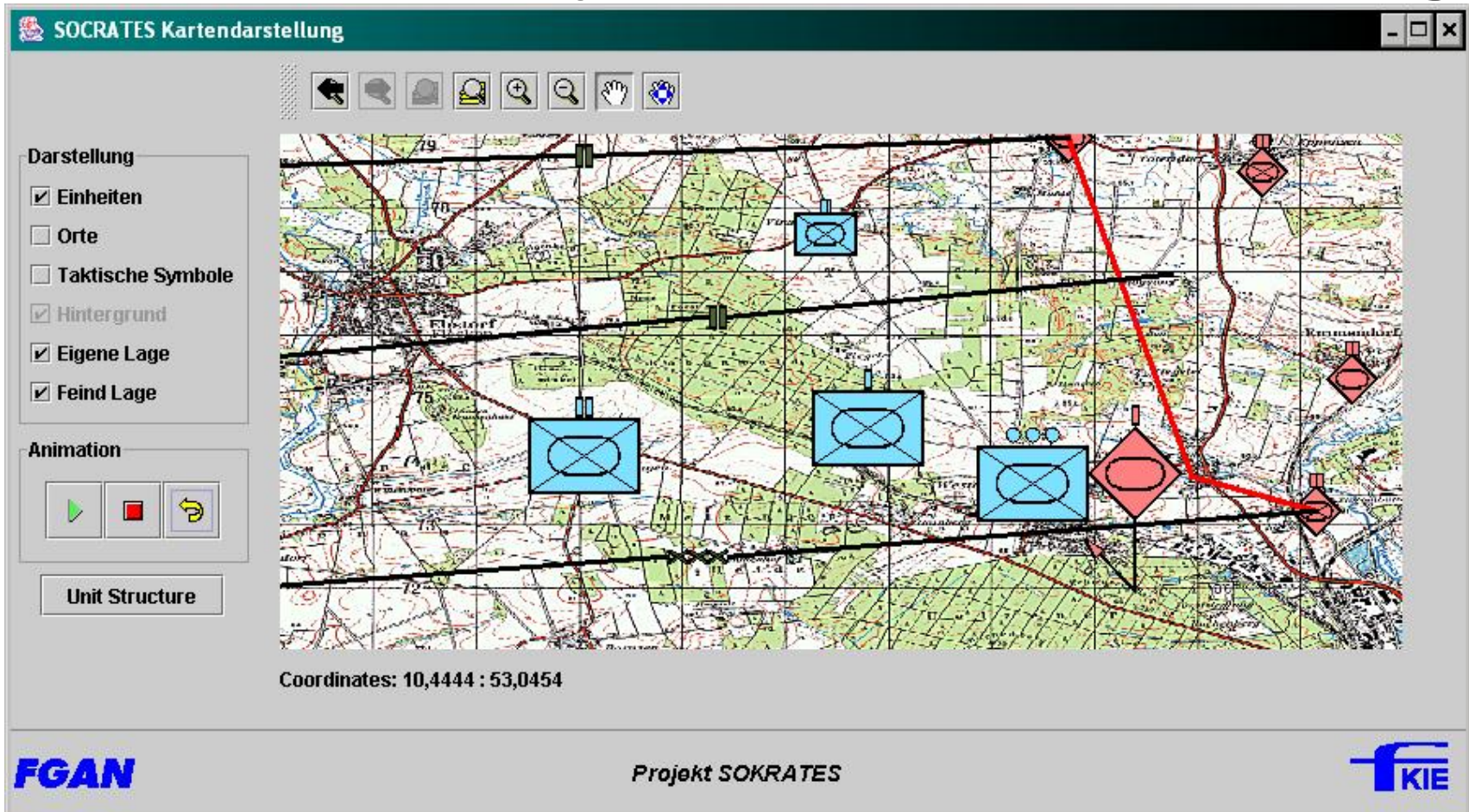
Platoon B:  
*4 hostile battle tanks  
approaching.*

reporting_data:	type:	move	
	agent:	type:	unit
		cat:	combat
		arm_cat:	armour
		mobility :	Indtrc
		size:	plt
		hostility:	hostile
	theme:	type:	battletank
		...	



# Example:

## The SOKRATES-System for Report Processing



Platoon B: 4 hostile battle tanks approaching.

# What can be learned from the example ?

By ontological means,

incoming information can be enhanced  
**quantitatively** as well as **qualitatively**:

more explicit

less ambiguous

less elliptical / more complete

The information will be interpreted by everyone alike.

# What can be learned from the example ?

After have ontological processes run,

there is a better understanding of the information exchanged.



More of its meaning is shared.

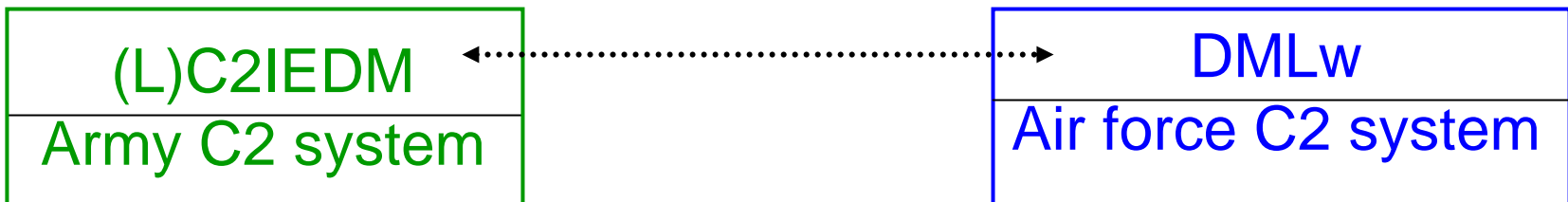
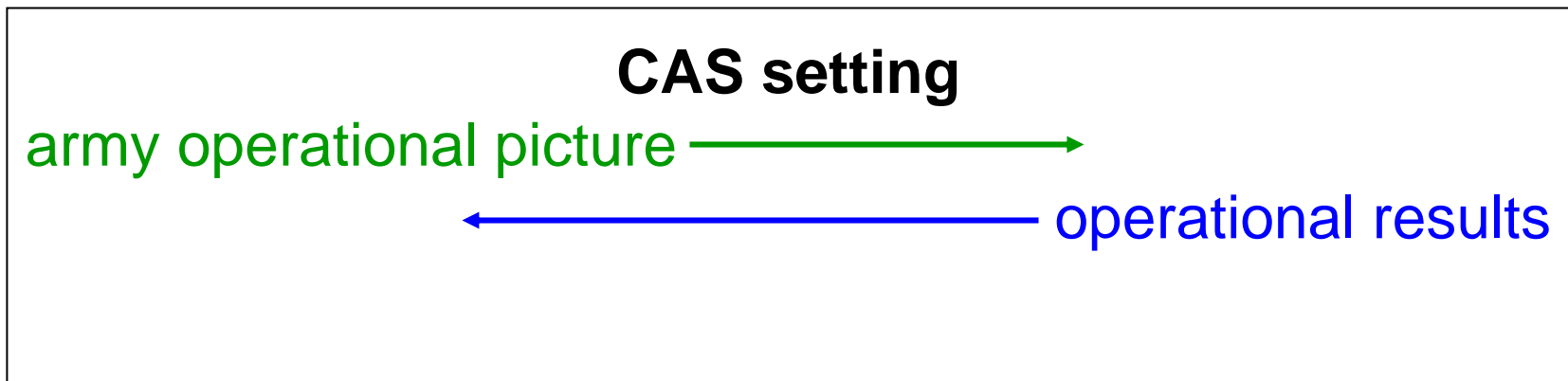


Semantic interoperability is improved.



# Outlook

*under development:*



# Outlook

*under development:*

